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Improvement of Power Quality in a Wind Farm Using Facts Controller

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ABSTRACT

This paper presents the implementations of Flexible AC Transmission (FACTS) Controller in wind farm. Several characteristics such bus voltage profiles, voltage transients, and total harmonic distortion are captured and investigated. The integration of Flexible Alternating Current Transmission Systems (FACTS) devices such as Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), Static VAR Compensator (SVC), and Static Compensator (STATCOM) into power systems was also studied. Models of common FACTS devices were developed and integrated into the power system model. The effect of installing FACTS devices on the power quality of power systems with a significant component of distributed energy resources was investigated. Simulation results with and without FACTs Controller have been validated with previous results and it gives better performance and efficiency.

Keywords: STATCOM, UPFC, SSS, SVC, Total Harmonic Distortion.

1. INTRODUCTION

The share of renewable energy resources in generating electricity has been increasing in most parts of the world over the past few years [1]. Until the 18th century people got all of their energy from renewable sources such as wind, water, sun, and wood. The use of fossil energy started during the 19th century only because of industrialization [2]. As of now, the world does not face any shortage of fossil energy, but confirmed reserves of oil and coal will be depleted before the end of this century . This has resulted in significant interest in renewable energy sources like solar energy, wind power, biomass, etc Power quality and voltage stability are major problems with modern power systems. Flexible AC transmission (FACTS) technology has been introduced to address these issues. FACTS technology helps in power control thereby enhancing the usable capacity [3]. FACTS technology is a collection of controllers, which can be applied either individually or in coordination with others to control the interrelated system parameters that govern the operation of transmission systems [4]. In this study, a 12 Bus power system model was developed in Matlab/Simulink using the Simpower systems module. The system is characterized and power quality issues with and without FACTS devices are simulated.

2. POWER QUALITY ISSUES

The increasing number of renewable energy source and distributed generator requires new strategies for operation and management of electric grid, in order to improve the power quality norms. International standards are developed by the working groups of Technical Committee-88 of the International Electro Technical Commission (1EC); IEC 61400-21 describes the -procedure of determining the power quality characteristics of wind turbine. Today in wind turbine generating system pulsecontrolledinverters are used. Due to the improvement in switching techniques, the voltage and current at the point of common connection

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can be made in sinusoidal form and at unity power factor so as to improve the power quality at PCC.Common power quality issues are Voltage fluctuation on grid, switching operation of wind turbine on the grid, voltage dips on the grid. Reactive power and harmonics.

3. FACTS CONTROLLERS

The application of FACTS devices to power system security has been an attractive ongoing area of research. In most of the reported studies attention has been focused on the ability of these devices to improve the power system security by damping system oscillations and minimal attempts have been made to investigate the effect of these devices on power system reliability Four types of FACTS devices are chosen in this study by considering all the above requirements. A brief description of each of the FACTS devices and their capabilities is given below.

3.1. Static Synchronous Compensator (STATCOM)

STATCOM is a Voltage-Source inverter which converts a DC input voltage into AC output voltage in order to compensate both active and reactive power [6]. The STATCOM based current control voltage source inverter injects the current into the grid in such a way that the source current are harmonic free and their phase-angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. The basic circuit model of STATCOM and its characteristics are shown in Fig. 1.1

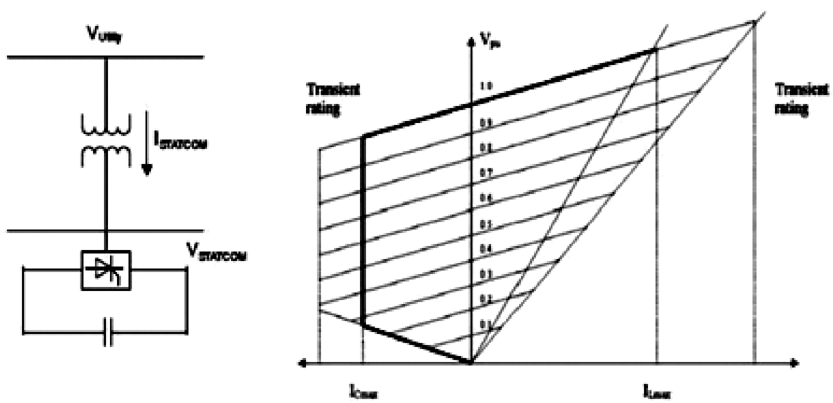


Figure 1: STATCOM and V-I characteristics

3.2. Static VAR Compensator (SVC)

The static VAR compensator is a shunt connected device, using thyristor switches and controllers, is already firmly established equipment for transmission line compensation. The SVC regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. The VAR

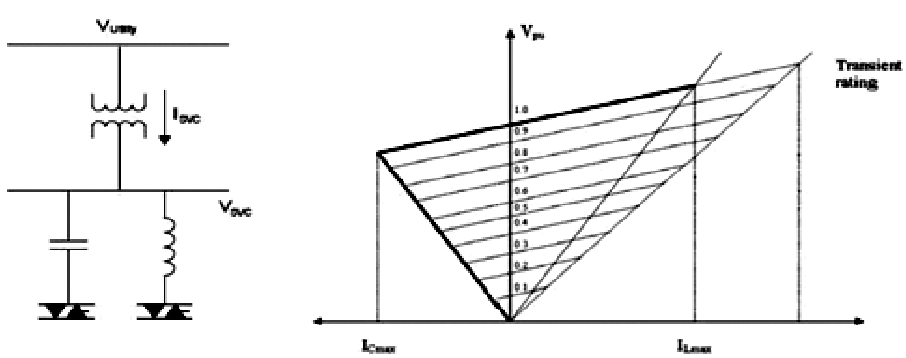
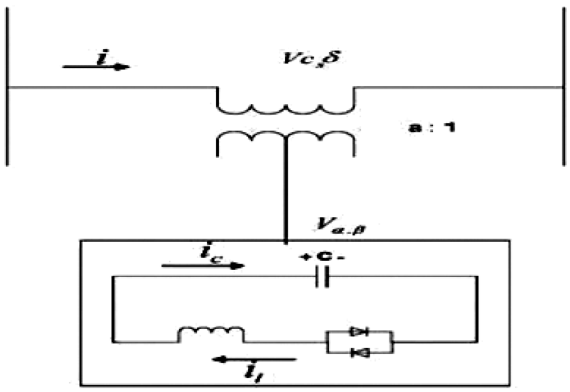


Figure 2: SVC model and VI characteristics

output of an SVC can be varied continuously and rapidly between the capacitive and inductive ratings of the equipment.

3.3. Static Synchronous Series Compensator (SSSC)

SSSC is a series- connected synchronous voltage source which helps to vary the effective impedance of a transmission line by injecting a voltage with appropriate phase angle in relation the line current. The objective of the SSSC is to control current and power flow through the line by controlling the exchange of reactive power between SSSC and the power AC system.



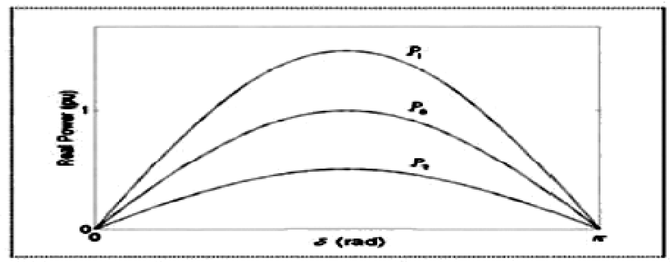


Figure 3: SSSC stability model and power angle characteristics

3.4. Unified Power Flow Controller (UPFC)

The UPFC is a device which can control simultaneously all three parameters of line power flow (line impedance, voltage and phase angle). Such “new” FACTS device combines together the features of two “old” FACTS devices: the Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC).In practice, these two devices are two Voltage Source Inverters (VSI’s) connected respectively in shunt with the transmission line through a shunt transformer and in series with the transmission line through series transformer, connected to each other by a common dc link including a storage capacitor. The shunt inverter is used for voltage regulation at the point of connection injecting an opportune reactive power flow into the line and to balance the real power flow exchanged between the series inverter and the transmission line.

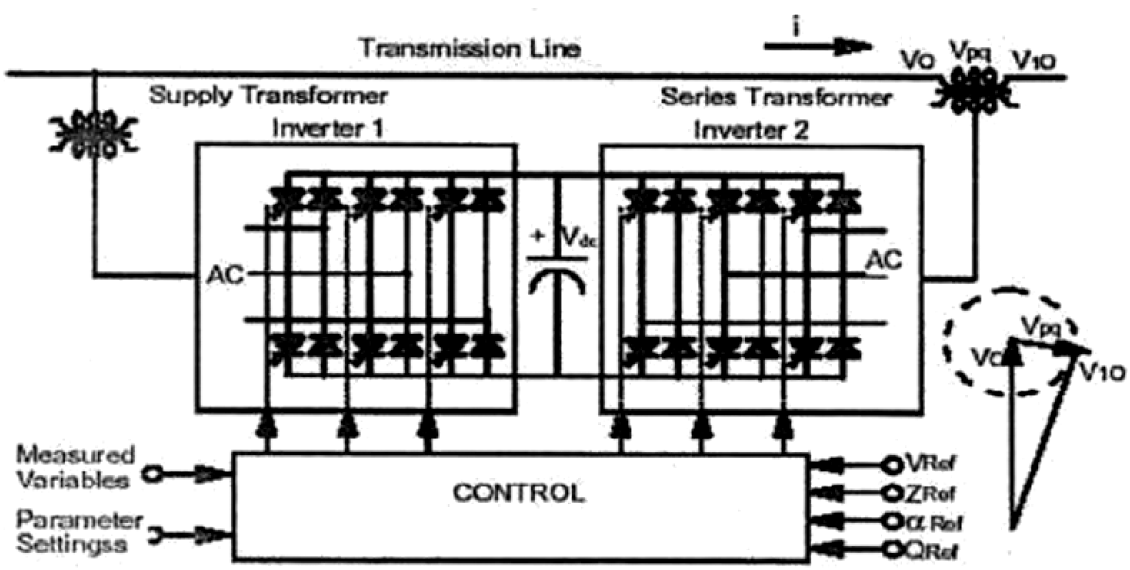


Figure 4: UPFC model and phasor representation of basic UPF

4. POWER SYSTEM MODELING

In this study a 12 Bus power system was modeled in the Mat lab/Simulink environment .The modeled system includes two wind farms (WFs) WF1 and WF2 which are connected to the 69kV loop power system at Bus 6 and Bus 3 respectively. The loads tapped on the weak loop system are 10 MW three phase dynamic loads. The system is supplied by two main substations, which are represented by two remote boundary equivalent sources at Buses 1 and 12. Among them, Bus 1 is the strong Bus with a short circuit capacity of about 4000 MVA. The WF2 at Bus 3 is a large wind farm with a total rating of 100 MVA. The WF1 at Bus 6 is located at the middle of weak 69 kV sub transmission system and the short circuit capacity at Bus 5 is about 152 MVA.

```
mysql> select *from t_ticket1_train1
+------+----------+---------+------+
| id   | source   | destn   | s_no |
+------+----------+---------+------+
|    1 | hwh      | bbs     |    1 |
|    1 | hwh      | kgp     |    2 |
|    1 | hwh      | bls     |    3 |
|    1 | kgp      | bls     |    4 |
|    1 | kgp      | bbs     |    5 |
|    1 | bls      | bbs     |    6 |
+------+----------+---------+------+
```

Figure 5: Simulink layout of the 12 bus system

The MATLAB/Simulink of a double-fed induction generator wind turbine is shown in Fig below

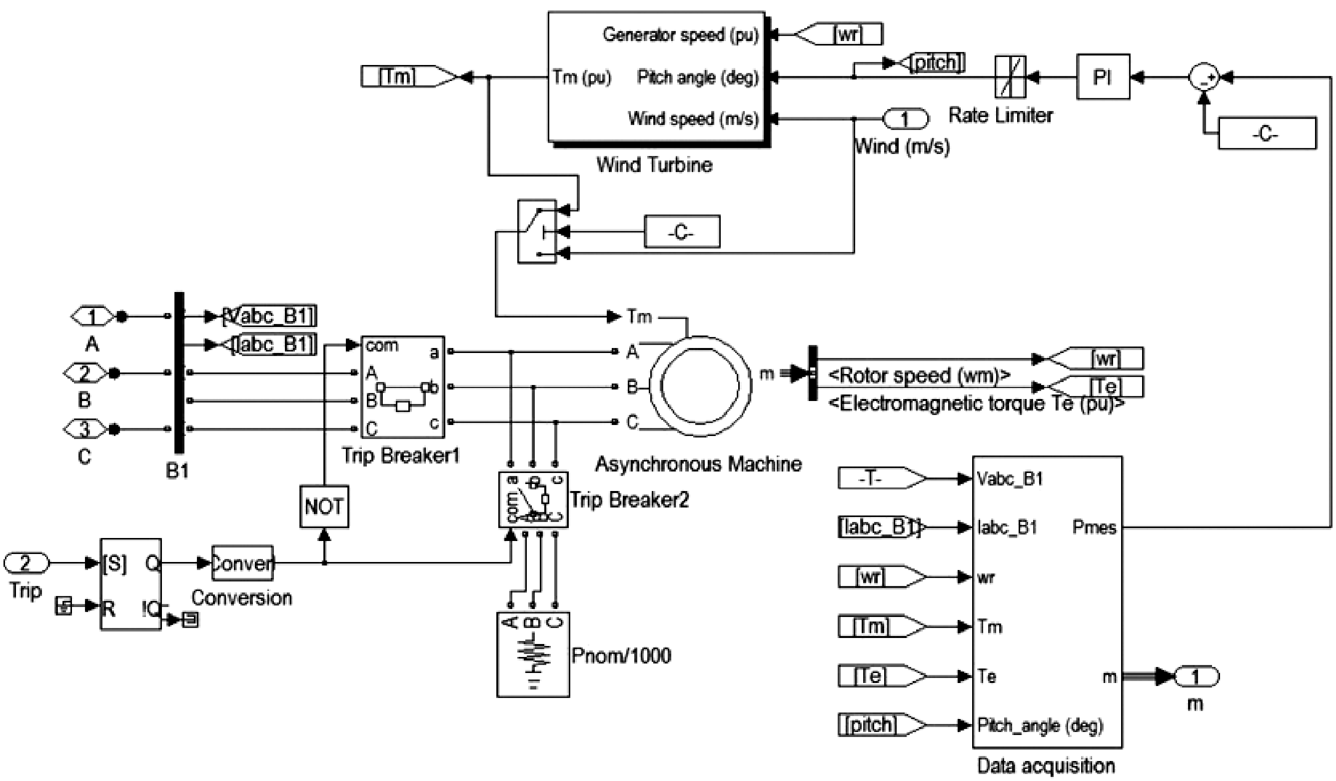


Figure 6: Internal model of wind turbine in MATLAB/Simulink

5. SIMULATION AND RESULTS

The simulation results of the designed 12 Bus model without any external device are shown in fig below

The simulation results of the designed 12 Bus model with STATCOM are shown below

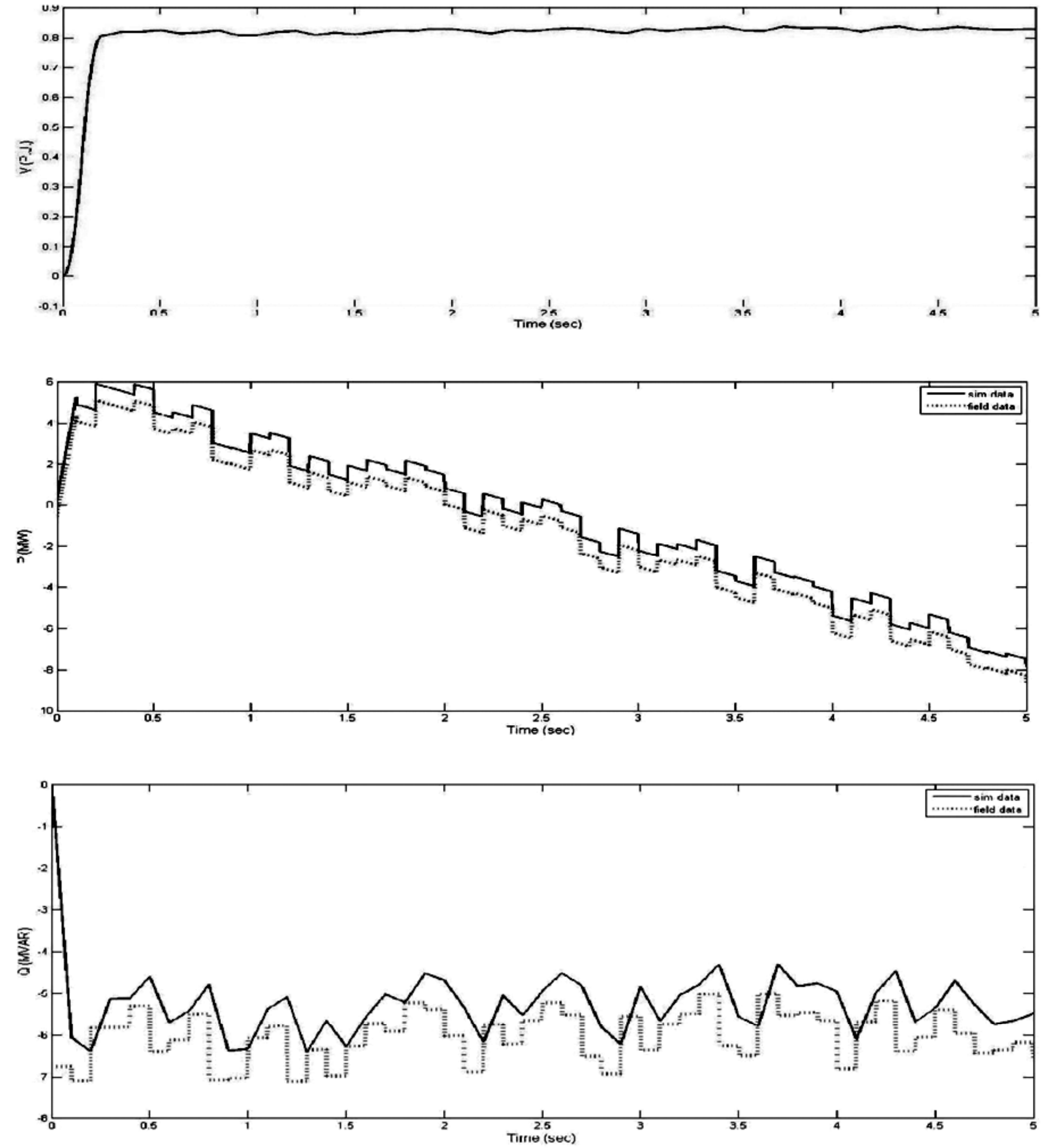
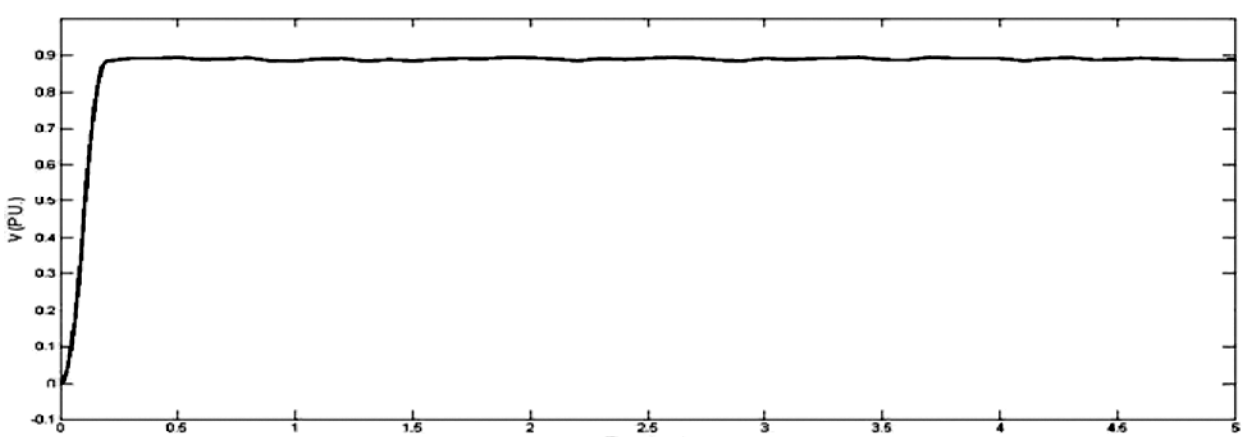


Figure 7: Without FACTS simulation results: Bus 2 voltage (top); Real power between Bus 2 and Bus 3 (middle); Reactive power between Bus 2 and Bus 3 (bottom).



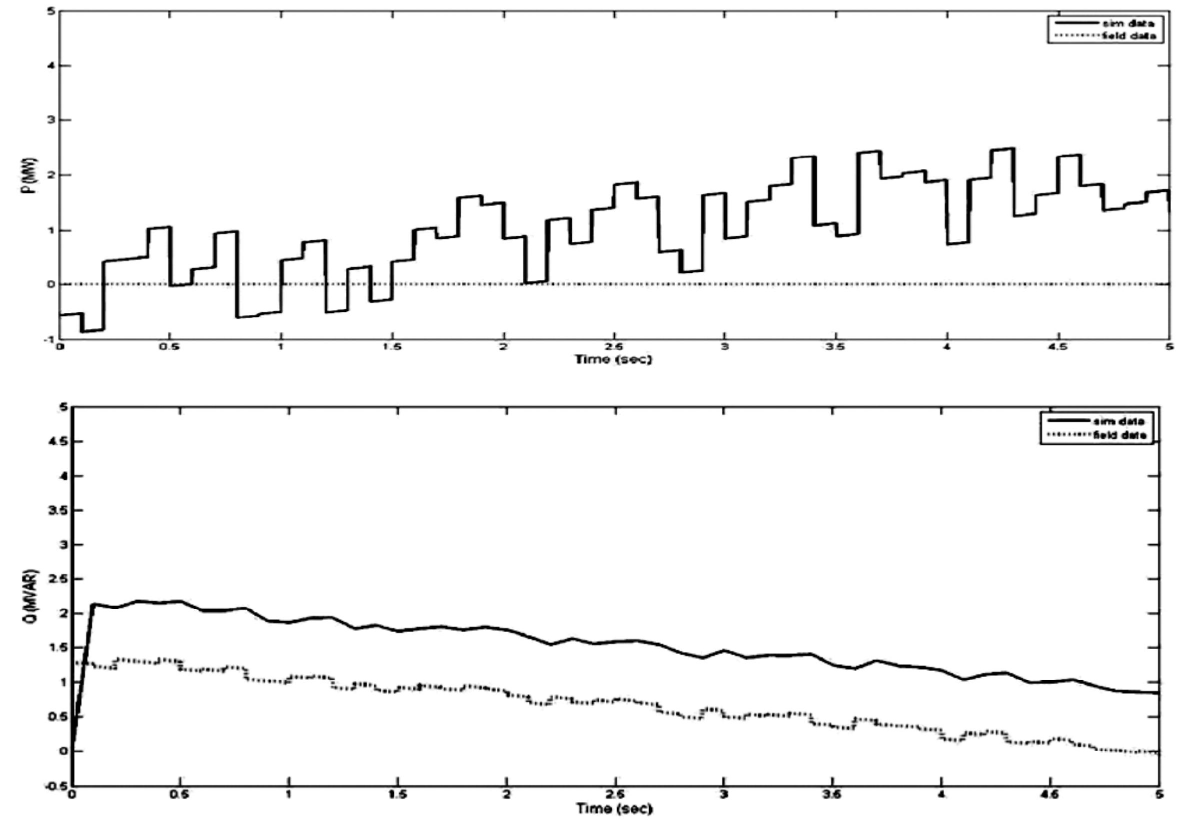
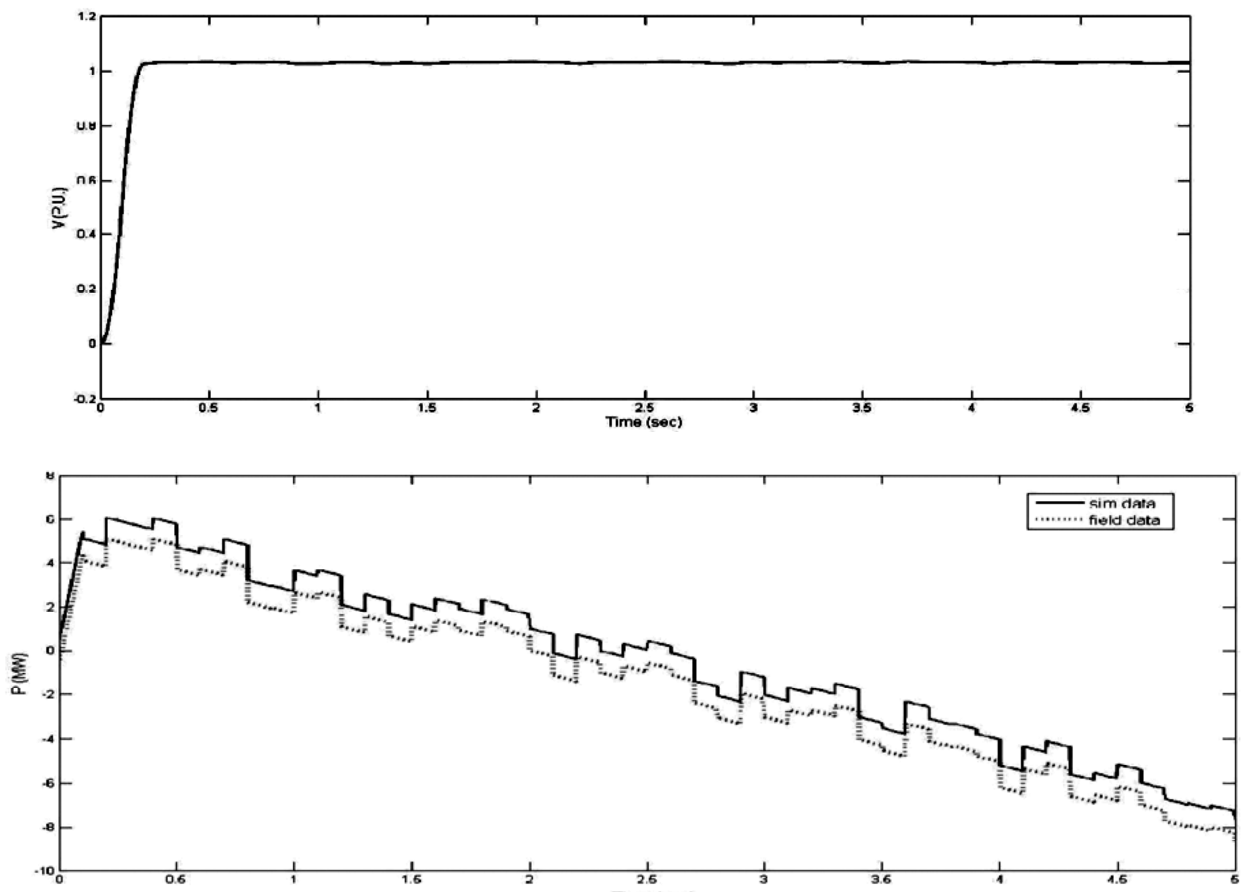


Figure 8: Without FACTS simulation results: Bus 3 voltage (top); Real power between WF2 and Bus 3 (middle); Reactive power between WF2 and Bus 3 (bottom).



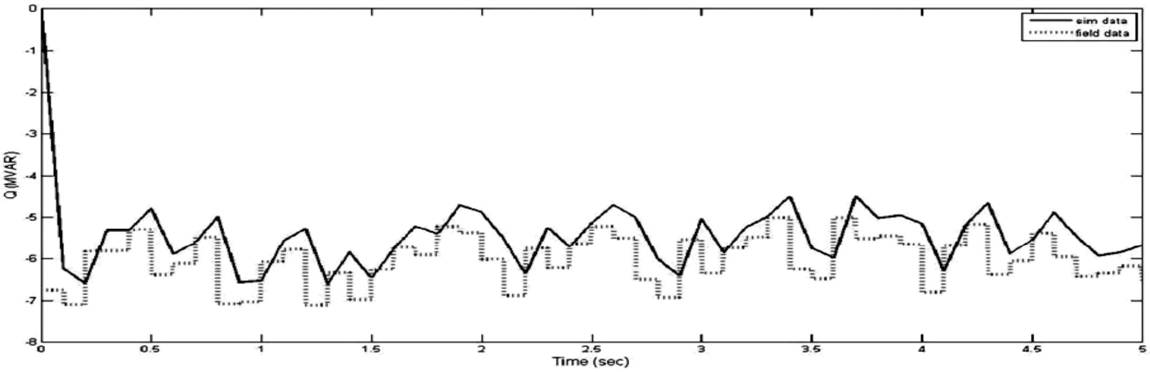


Figure 9: STATCOM device simulation results: Bus 2 voltage (top); Real power between Bus 2 and Bus 3 (middle); Reactive power between Bus 2 and Bus 3 (bottom).

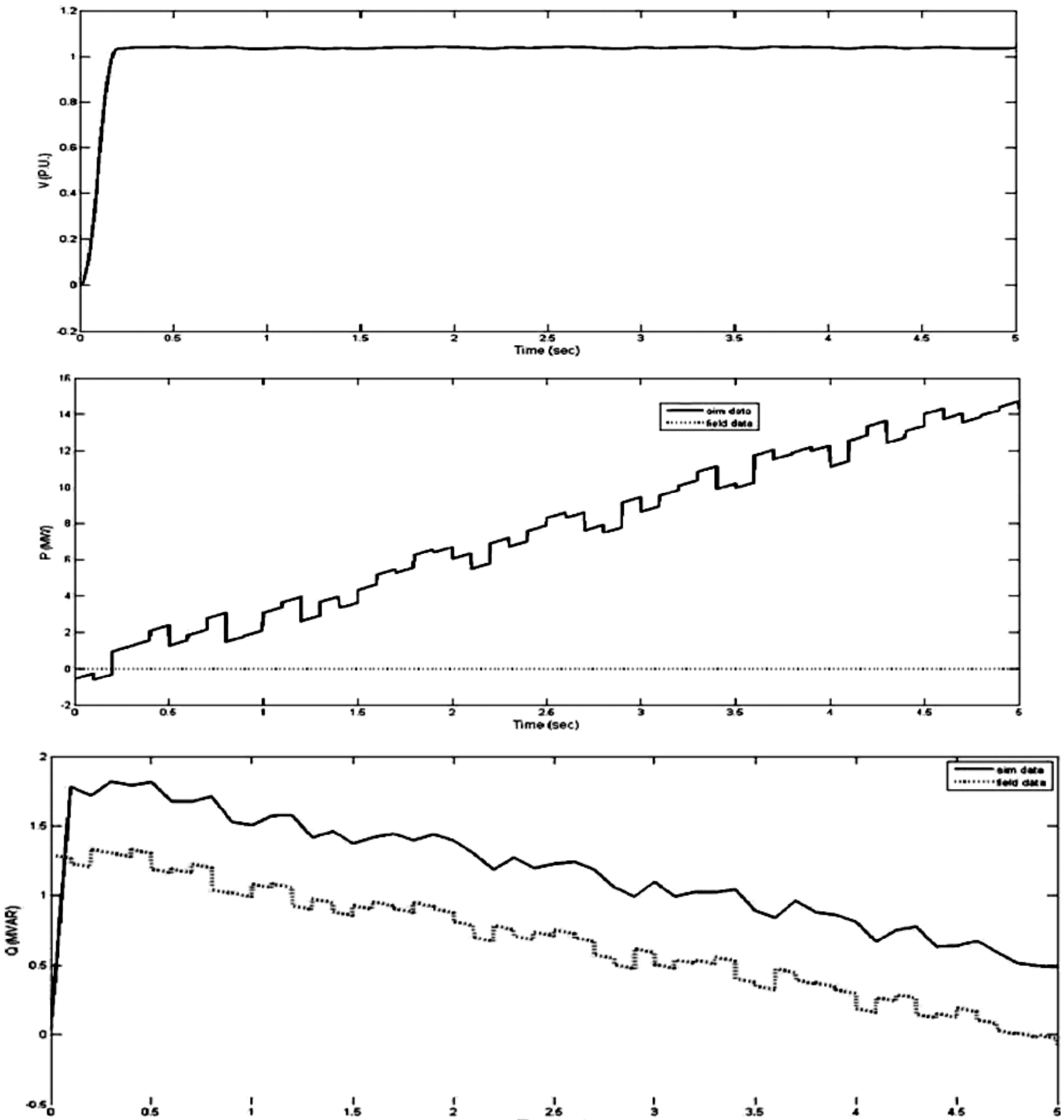


Figure 10: STATCOM device simulation results: Bus 3 voltage (top); Real power between WF2 and Bus 3 (middle); Reactive power between WF2 and Bus 3 (bottom).

The simulation results of the designed 12 Bus model with SVC are shown below

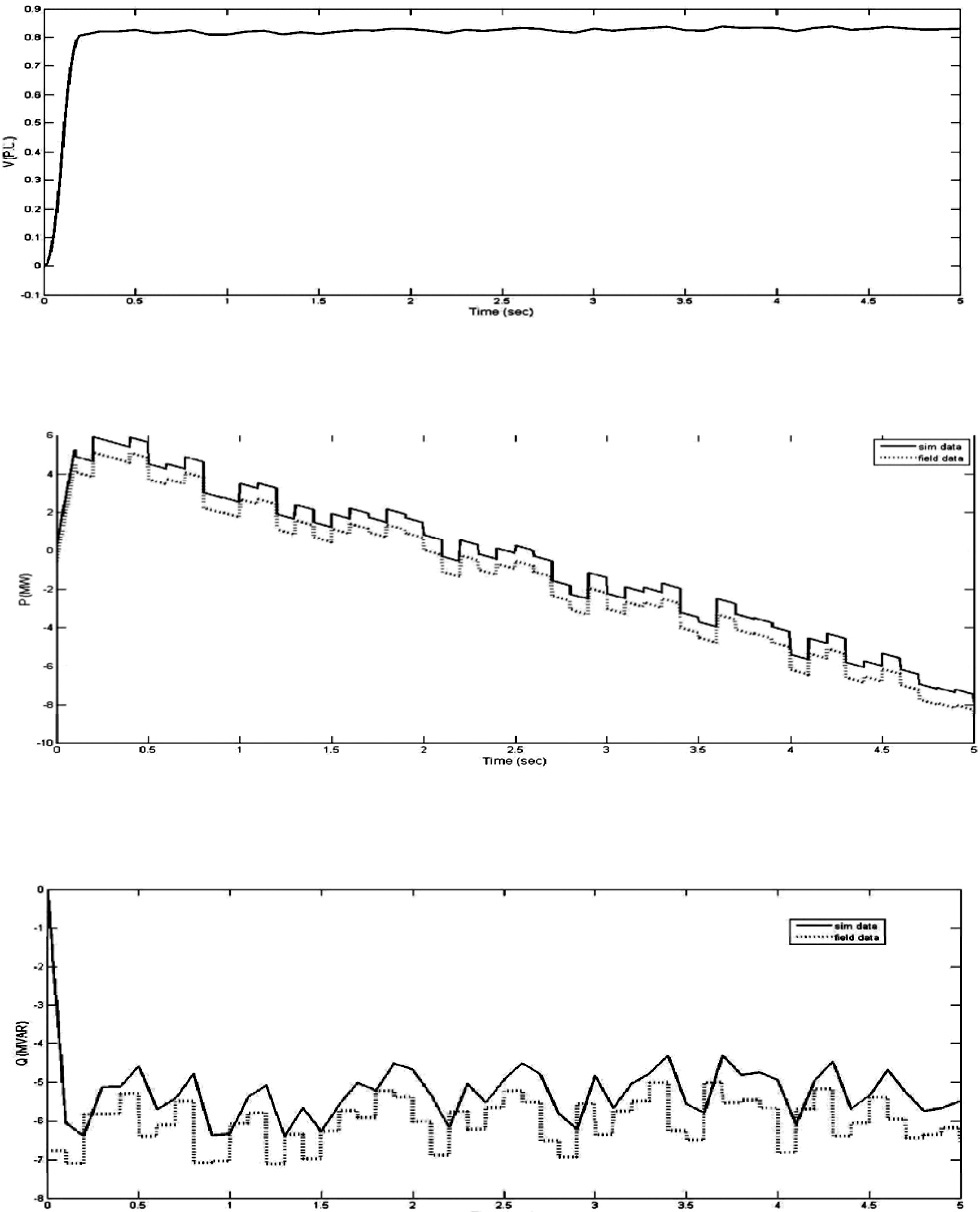


Figure 11: SVC device simulation results: Bus 2 voltage (top); Real power between Bus 2 and Bus 3 (middle); Reactive power between Bus 2 and Bus 3 (bottom)

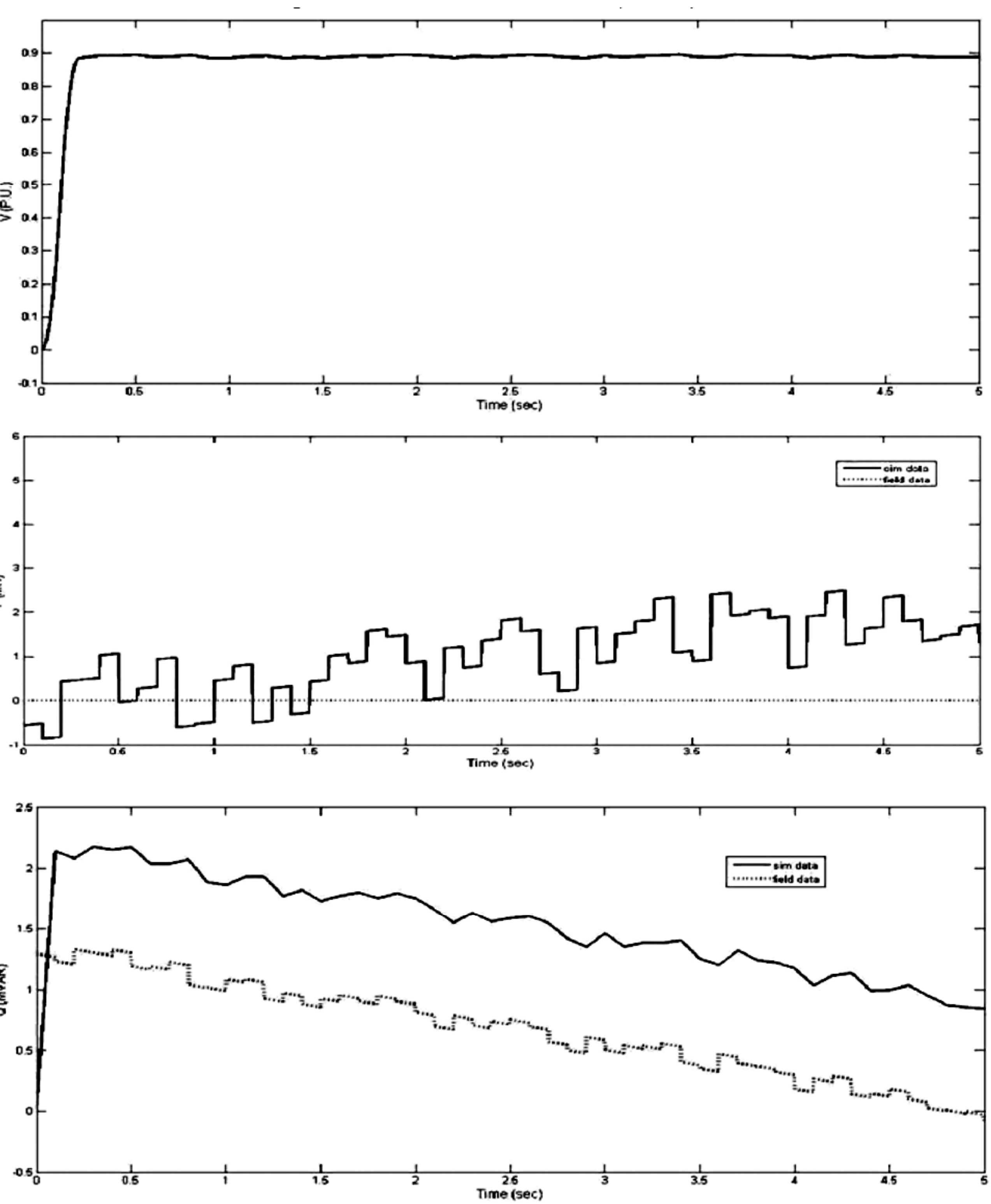


Figure 12: SVC device simulation results: Bus 3 voltage (top); Real power between WF2 and Bus 3 (middle); Reactive power between WF2 and Bus 3 (bottom).

The various simulations are done by installing the FACTS devices such as STATCOM, SVC, SSSC and UPFC in the closed loop system. By considering the simulation results their voltage, real power and reactive power values at different Buses are shown in Table 1.1 and Table 1.2 respectively

From the above tables it is clear that with installation of FACTS device there is an improvement in power quality. A change in voltage variation is observed with the installation of Facts Devices. From the above tables it is clear that the STATCOM and SSSC show better improvement in power quality when compared to SVC and UPFC.

The total harmonic distortion at different Buses are simulated and their values are shown in Table 1.3.

Table 1
Comparison of Simulation results with Field Data

Components	*Bus2 to Bus 3*			*Bus 3 to WF2*			*Bus 4 to Bus 5*			*Wf1 to Bus 5*		
	PMW	*QMVA*	*VP.U.*	*PMW*	*QMVA*	*VP.U.*	*PMW*	*QMVA*	*VP.U.*	*PMW*	*QMVA*	*VP.U.*
Field Data	3.7	-6.8	1.05	-3.2	1.2	1.03	4.2	-3.2	1.01	0.0	1.1	1.02
Wind farm Without FACTS	3.7	-6.1	0.83	0.5	1.3	0.91	3.9	-3.3	0.93	0.0	1.05	0.91
Wind Farm with STATCOM	4.1	-6.4	1.05	3.3	1.6	1.03	4.5	-3.5	1.03	0.0	1.15	1.03
Wind farm with SVC	3.5	-6.3	0. 9	0. 9	1. 2	0.88	4. 2	-3.6	0.93	0.0	1.07	0.95
Wind Farm with UPFC	4.2	-6.5	0.93	1.1	1.5	0.92	4.2	-3.3	0.91	0.0	1.1	0.93
Wind Farm with SSSC	4.2	-6.1	1.05	3.5	1.5	1.02	4,4	-3.5	1.05	0.0	1.09	1.05

Table 2
Voltage Profile at all Buses for Different Simulations Measured in (P.U.)

V(P.U.) devices	*V2(V)*	*V3(V)*	*V4(V)*	*V5(v)*	*V6(V)*	*V8(V)*	*V11(V)*
Without FACTS	0.85	0.83	0.84	0.88	0.92	0.87	0.87
STATCOM	1.04	1.07	1.05	1.15	1.14	1.08	1.08
SVC	0.85	0.87	0.88	0.9	0.92	0.9	0.9
SSSC	1.04	1.03	1.05	1.15	1.15	1.08	1.08
UPFC	0.87	0.88	0.91	0.93	0.93	0.89	0.89

Table 3
Total Harmonic Distortions at Different Buses

THD	*B1*	*B3*	*B5*	*B6*	*B8*	*B12*
Without FACTS	24.95	24.9	24.94	25.04	24.94	24.95
STATCOM	0.21	0.39	0.86	0.64	0.86	0.21
SVC	10.36	10.33	10.31	10.33	10.31	10.36
SSSC	10.38	10.43	10.43	11.25	10.58	10.38
UPFC	10.36	10.36	10.36	10.35	10.36	10.36

From the above table it is clear that the wind farm model with STATCOM reduces harmonic content to some extent when compared to other FACTS devices. The other FACTS devices also help in reducing the harmonic content when compared to the model without any FACTS device, but not as good as the model with STATCOM

6. CONCLUSION

FACTS devices such as STATCOM, SVC, SSSC, UPFC are placed at suitable locations in a 12-Bus multi-machine power system model with large renewable energy sources. Simulations show that there is a significant improvement in power quality due to the FACTS devices. When comparing FACTS devices for better power quality, it is clear that STATCOM and SSSC are superior to other FACTS devices.

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